# PERFORMANCE EVALUATION OF EMERGENCY WATER SUPPLY SYSTEM IN KOREA

By

**HONG, Jaechang**

**CAPSTONE PROJECT**

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

For the Degree of

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Committee in charge:

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Approval as of December, 2018

## ACKNOWLEDGEMENT

Finishing this project was not an easy task for me. I have spent a lot of my time with this project while I was in KDI. I owe my deepest gratitude to many people who always support me. To be honest, it was not possible to make this project done without getting support from them. Therefore, I would take this opportunity to thanks these people.

First, I would like to express my high gratitude to my major supervisor, Dr. Dong Young Kim, who agreed to be my research supervisor, and Dr. June Soo Lee, my committee supervisor. Their guidance and suggestions were so important in research.

Second, I would like to offer my special thanks to professors in KDI School who taught and gave very valuable lessons which will be really helpful broadening my perspective.

Third, I would like to thank K-water for choosing me as Global Water Management and Policy. I am so thankful for giving me a chance to prove my commitment and qualification that I could finally finish my master degree.

Finally, I would like to say thanks sincerely to my wife, all K-water colleagues and KDIS friends and strangers who was always with me during my time in KDI. Without getting their supports, I could not make my master degree done easily.

# EXECUTIVE SUMMARY

As the importance of safety increases, constructing WSS for crisis response is also becoming important. The purpose of EWSP is to identify the exact situation of interruption when crisis happen such as a pipeline accident, and then to minimize its damage. Nevertheless, EWSP for crisis management on WSS has been analyzing the maintenance result every year with just two indicators, which are 'the Ratio of emergency water supply' and 'the Area of 100% available supply.'

As the result of case study through 10 selected indicators, although it is possible to supply water within the recovery period of, especially 24 hours, we found vulnerability exists in overall operation process. Moreover, the fact that not only the adjustment of supply interruption area but also the restriction of water and the maintenance of appropriate pressure can also have a great impact on risk situation so further research that can be reflected in the evaluation indicator group is also required.

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# Chapter 1: Introduction

## 1.1 Context of Problem.

Since early 1960's, K-water has begun to supply water to nationwide starting from Ulsan and Changwon, and now the rate of water usage in Korea has grown to approximately 98.8% (Ministry of Environment, 2015). However, in 2011, due to a serious accident which stopped supplying water for about three days in Gumi city, all citizens and industrial complexes had been in trouble.

One of the reasons is the aging of waterworks facilities, which were intensively constructed in the economic growth period. As result, more than 50 accidents have been occurring annually, and other reasons are climate change which causes floods with exceeding standards on waterworks facilities; recent frequent earthquakes are also threatening. Even if situations where such operations and management are becoming increasingly complex, customer expectation on quality service for suppling the tap water safely is getting higher.

In case of crisis or disaster situation on Water Supply System, hereafter WSS, although the reason of accidents such as old infrastructure, power interruption, and floods are various, it is always perceived as failure of the management, leading to degradation of external image of the supplier. The impact of water supplying interruption is tremendous. This is because the accident incurs not only inconvenience for people's daily life, but also social disruption and economic damage such as vehicle, flood damage and traffic control. For example, 170,000 citizens sued K-water for 3.4 billion won in damages from the accident in 2011. In case of supply water for industry, the interruption of supply for merely 20 minutes resulted in damage of 70.7 billion won for 26 companies in Yeosu city.

## 1.2 Statement of Problem

### 1.2.1 Stabilization Plan of the Wide and Industrial WSS

According to K-water report (2016), risk on the interruption for water supply is increasing by the aging facilities. The report predicts that the old aging pipelines will be expanded from 461 km (8.8%) in 1973 to 863 km (16.4%) in 2020 and 2,586 km (49.1%) in 2030. In the last three years, pipeline accidents actually have increased annually from 23 cases in 2015 to 33 cases in 2017. The important point is that in order to provide stable water supply to people, there is a need to fundamental facilities, such as improvement on the aging pipelines, double pipelines, and connection between systems, as well as a strengthened crisis response capability.

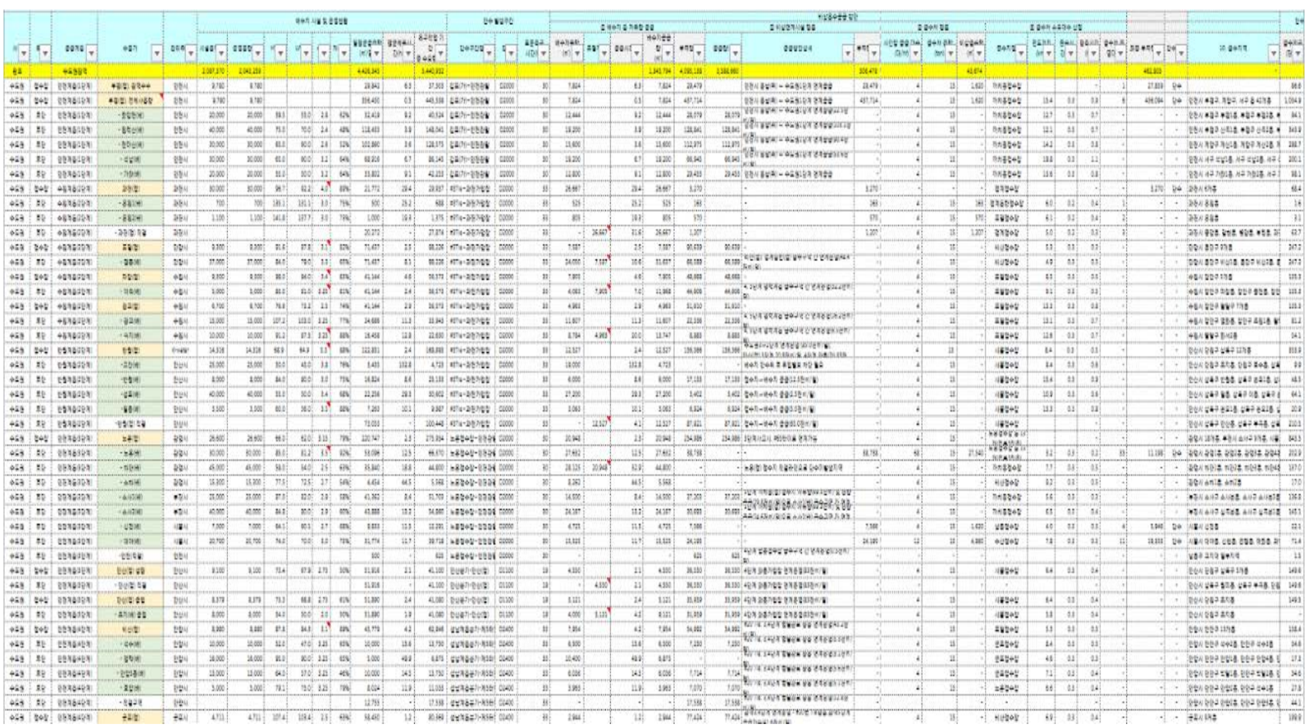
For this reason, K-water has established plan to stabilize the water supply for wide-area and industrial in 2011 for improvement of old pipe lines of 992km and construct double line of 937km, by investing four trillion won in 64 projects till 2030. 13 projects have been completed by 2017 and 14 projects are under construction. In order to complete the stabilization plan by 2030, it is necessary to reflect three to four project per year in the budget. However, performance so far is poor compared to the plan due to reasons of low profitability, complicated procedure and the reduction on SOC budget by government.

### 1.2.2 Emergency Water Supply Plan for the ability on Crisis response

As supplier, even if in such limited conditions, it is essential to provide stable supply which recovers inconvenience and loss caused by tap water quality and interruption. The Master plan (Ministry of land, 2015) suggested the necessity of method for suppling without interruption when emergency situations happen by maximally utilizing sub-element existing WSS supply, operation and management system. As part of that plan, Emergency water supply plan, hereafter EWSP, was set up for crisis situation in 2011.

The purpose of EWSP is to identify the exact situation of interruption when crisis happen such as a pipeline accident, and then to minimize its damage. In case of an accident in each section, the whole wide-area waterworks are subdivided by major node and branch point, and customers using large-sized water. By this method, EWSP consists of 1) the use of storage capacity such as reservoirs, 2) the use of emergency connection facility, and 3) the use of water supply vehicle. In addition, if the supply amount is insufficient even after utilizing the methods above, it is possible to estimate the scale of stop-supply. There are 222 Emergency connection facilities for EWSP in the 2016 annual report: 184 Wide-Wide cases and 38 Wide-Local cases.

***Figure 1:*** Summary table of the Emergency Water Supply Plans (EWSP) in K-water



Source: Excel template of K-Water

### 1.3 Research Question

As the importance of safety increases, constructing WSS for crisis response is also becoming important. Nevertheless, EWSP for crisis management on WSS has been analyzing the maintenance result every year with just two indicators which are “the Ratio of emergency water supply” and “the Area of 100% available supply”. Annual report (2016) from K-water noted that the former ratio reached 89.4%, and the next indicator was 67% by analyzing the total of 5,247km divided into 340 sections. On the other hand, the area of available supply to 80% was about 81.7% of the total extension. Actually, through managing indicators, K-water is able to proceeding with establishment and discovery of the connection facilities annually, but there are several limitations.

First of all, it is mostly composed only of physical measurements and connections, and just numerically showing that the most cases can serve to supply without interruption or any issues, such as complaints, inconvenience and quality of service.

However, Crisis Response Manual (2018) explains that it is necessary to respond flexibly to the risks by adapting to unpredictable situations, because there are many variables such as time and place and type of risk when crisis happens. Especially in case of big-scale crisis, systematic response is needed for long-term, so the substantial plan on field operation should be practically established. In order to do this, it is essential to precisely recognize the risk of both current status and owned infrastructure to participants of plan, decision makers and field operators. In other words, this means that the proper system and methods are needed for crisis response, as well as the fundamental improvement of facility in vulnerable situations that is likely to occur as the probability of exposure of the disaster, such as the aging of pipelines.

### 1.3.1 The review on the Necessity of Performance Indicators for Evaluation

Accordingly, this paper will examine how to effectively evaluate the WSS on risk situation for crisis response by developing the performance indicators, hereafter PIs. The recent report in K-water (2017), "Development of Techniques for Reconstructing and Operating Water Belt," explains that despite necessity introducing the emergency water supply system even in local-area has been rising, there is still lack of efficient methods based on reasonable standards and linkages.

This paper will quote many parts of the previous study called "Evaluation of the effectiveness of performance indicators for waterworks and development of the application system" to explain the need and qualification of the indicators.

### 1.3.2 Purpose of Indicator Development

International Standardization Organization, hereafter ISO, insisted that standardization of water supply and wastewater services aims to quantify its services. The purpose is to improve the efficiency of development, operation and management of water supply and wastewater systems. This can be done by developing clear definition indicators to monitor and evaluate all conditions in ISO / TC224 called "Services related to drinking water supply and wastewater and stormwater systems."

First, standardized indicators will enable objective comparison of business performance, and pressures to improve efficiency in inefficient locations. In addition, the will provide an overview of how management can operate and maintain the suitable system, which can significantly improve the quality of service.

### 1.3.3 Required Condition of Indicator

Supplier should be able to objectively evaluate its own work and actively make use of it. In other words, PIs should be quantified as much as possible so that subjective judgment of evaluation can be avoided, and performance indicators that are suitable for evaluation purposes should be balanced without duplication with performance indicators. It is also important to create performance indicators that are not too complex and difficult to understand.

## 1.4 Research Structure

This study consists of four chapters. Chapter one describes the context of problem, the statement, research questions and structure. For gathering data, chapter two reviews the literature of previous study related to the performance indicators on water supply system. Following the results from chapter two, Chapter three proposes the PIs and analyzes the actual case in K-water by using proposed PIs. The last chapter includes conclusion and policy recommendation for this study.

# Chapter 2: Field research for gathering data (document analysis)

In this study, the descriptive research will be used. Researcher collects secondary data from international organizations and use materials from journals as well as research conducted domestically. The research is mainly selected from PIs that are most suitable for K-water operation situation by analyzing data of international accredited institutions such as IWA, JWWA and the previous study in K-water. The selected performance indicators are applied to actual cases for extracting and then the result of case study provides an opportunity to objectively evaluate the current status of WSS on risk situation and to present policy recommendations.

## 2.1 The Performance Evaluation System and Indicators from IWA

The International Water Association, hereafter IWA, is the world's largest organization representing 130 countries in the water and sanitation sector, and has developed and published a performance indicator system. This performance indicator system is utilized as a tool that can manage the water service business effectively and appropriately independent of the level of development, climate, population, and cultural characteristics of a specific area (Choi, 2008). The system was also developed to be used as a performance indicator, covering all areas of water management including water source, personnel, physical, operational, quality of service, and finance (Cabrera Jr., et al., 2006).

Two categories of the operational group and Quality of service indicators deal with related PIs, such as supply failure and supply interruption in crisis management. The most significant feature is that there are indicators related to factors of inconvenience for customers when situations like supply interruption occur. Not only the pressure, continuity, water quality and interruption, but also the customer complaints belong here. As result from the overall analysis, Table 1 below shows the PIs that are likely to associate with crisis or risk.

| CODE | INDICATOR | CONCEPT |
|---|---|---|
| **Operational indicators (Op)** | | |
| **FAILURES** | | |
| **Op 26** | **Mains failures** | Number of mains failures during the year, including failures of valves and fittings |
| **Op 27** | **Service connection failures** | Number of service connection failures during the year |
| **Op 28** | **Hydrant failures** | Number of hydrant failures during the year |
| **Op 29** | **Power failures** | Number of hours during the year each pumping station is out of service or is reliant on standby power generation due to power supply interruptions |
| **Quality of service indicators (QS)** | | |
| **SERVICE** | | |
| **QS 09** | **Pressure of supply adequacy** | Number of delivery points that receive and are likely to receive pressure equal to or above the guaranteed or declared target level at the peak demand hour (but not when demand is abnormal) |
| **QS 10** | **Continuity of supply** | Number of hours when the system is pressurised during the year |
| **QS 11** | **Water interruptions** | Population subject to a water interruption with duration of the interruption in hours |
| ***QS 12*** | **Interruptions per connection** | Total number of interruptions<br>* This indicator should only be used if QS11 cannot be calculated. |
| **QS 13** | **Population experiencing restrictions to water service** | Population affected by restrictions to water service with duration of the restrictions to water service in hours |
| ***QS 14*** | **Days with restrictions to water service** | Total number of days with restrictions to water service during the year / 365 × 100<br>* This indicator should only be used if QS13 cannot be calculated. |
| **CUSTOMER COMPLAINTS** | | |
| **QS 22** | **Service complaints** | Number of complaints of quality of service during the year |
| • | **QS 23–pressure complaints** | Number of pressure complaints during the year |
| • | **QS 24–continuity complaints** | Number of continuity complaints during the year |
| • | **QS 25–water quality complaints** | Number of water quality complaints during the year |

| | | |
|---|---|---|
| • | **QS 26–interruptions complaints** | Number of interruptions complaints during the year |

***Table 1:*** Performance Indicators related to Crisis in IWA

Source: Performance indicators for water supply services, IWA Publishing 2006

## 2.2 The Performance Evaluation System and Indicators from JWWA

The Japan Water Association, hereafter JWWA, announced "Guidelines for the management and assessment of a drinking water supply service (2005, JWWA Q100)" in 2005. There is a total of 137 performance indicators, which are divided into six categories: relief (22), stable (33), sustainable (49), environmental (7), managemental (24) and international (2).

Risk-related indicators are covered under the "stable" category directly aimed at "secure living water stably anytime and anywhere." One of the noticeable features is the indicator that evaluates earthquake resistance, according to the regional characteristics of Japan, which frequently have disasters such as earthquakes and floods. Other features are the 2203 and 2204 indicators that measure the ability of crisis response. As mentioned above, "the ratio of emergency water supply" refers to the emergency supply ratio as a percentage of the total supply volume during the period for accident recovery. The concept of that indicator is applied when the water purification plant stops for a maximum of 24 hours.

***Table 2:*** Performance Indicators for Risk Management in JWWA

| CODE | ITEM | Definition |
|---|---|---|
| **Risk Management** | | |
| 2201 | Water quality accident number of water source | Annual water source Water quality incidents |
| 2202 | Accident rate of main line | Number of accidents on main line |
| **2203** | **Accident water distribution rate** | **Water distribution amount at accident per average daily water distribution amount** |
| **2204** | **Water supply population rate at accident** | **Water supply population at accident** |
| 2205 | Water supply base density | Distribution reservoir and Number of emergency water tank |
| 2206 | Raw material lubricity between lines | Raw water sending capacity per receiving side water purification capacity |
| 2207 | Water purification facility seismic resistance rate | Capacity of water purification facility subject to earthquake resistance measures |
| 2208 | Pump room earthquake resistance rate | Capacity of pumping facility with earthquake resistant measures |
| 2209 | Distribution reservoir earthquake resistance rate | Discharge reservoir capacity subjected to earthquake resistant measures |
| 2210 | Earthquake resistance rate of pipeline | Extension of earthquake proof pipe |
| 2211 | Days for storing chemicals | Average chemical storage per average daily usage |
| 2212 | Fuel stockpile number of days | Average fuel storage per daily usage |
| 2213 | Water tanker holding degree | Number of water supply vehicles |
| 2214 | Portable poly-tank Retention | Portable poly-tank · number of poly packs |
| 2215 | Water tank reservoir for in-vehicle use | Total capacity of in-vehicle water supply tank |
| 2216 | Private power generation facility capacity ratio | Private generator facility capacity |
| 2217 | Facility rate with alarm | Number of facilities with alarm |

Source: JWWA Q100, JWWA Publishing 2005

## 2.3 Previous study related to Performance Indicators in K-water

The purpose of the "Development of Techniques for Reconstructing and Operating Water Belt" by K-water is to (1) develop procedures (crisis response, water quality, energy) to evaluate the adequacy and operational efficiency on grid system of wide-area and local WSS, and (2) provide a comprehensive evaluation process, based on crisis response and water quality residual chlorine, DBPs, quality equalization to establish grid system of wide-area and local WSS.

In this study, the proposed concepts for efficiency evaluation are as follows: Quantitative efficiency, water quality efficiency, supply stability, and public service efficiency. This study is actually confined to the grid of wide and local WSS and emphasizes strengthening the management base and improving the level of service among business operators. This is because the objective is to carry out a quantitative evaluation of the expected effect of integrating or sharing the manpower, facilities and resources related to management among operators. However, the "Supply Stability" indicators, which assesses the availability of supply without interruption, will be used in this study as the indicators to assess emergency response capability.

The methods of evaluating the efficiency of the supply stability expected by using the grid system wide-area and local system are as follows.

(1) Available supply population for emergency: Indicator for evaluating the ability of emergency response by using connection with wide-area waterworks on crisis situation

(2) Time with restriction to water supply: Indicator for the number of total restricted hours considering the water supply-restricted population in the management area. The PI can evaluate the change in the damage scale when the connection with wide-area waterworks use for

crisis situation. Especially, the restriction includes both poor water-flow and completely interruption.

(3) Interruption Population rate: Indicator for percentage of the interrupted population that occurred in one year relative to the total supplied population in the management area. This PI can evaluate the change in the damage scale, as #2.

(4) Budget for dealing with crisis management: Indicator for budgets spent to cope with unanticipated emergencies, such as natural disasters, droughts, accidents, etc.

(5) Average recovery time without notification: Indicator for the percentage of the total supply restricted hours relative to the total time of restoration without any notification.

***Table 3:*** Formulas by Indicator

| Indicators | | Formula for Calculating |
|---|---|---|
| **Supply Stability** | | |
| (1) | **Available supply population for emergency** | Population to Available supply for Emergency / Population to daily supply |
| (2) | **Times with restriction to water supply** | Times of restricted supply x population of restricted supply / population to supply |
| (3) | **Interruption Population rate** | Population with interruption / population to supply |
| (4) | **Budget for dealing with crisis management** | Budget for dealing with crisis management / total budget |
| (5) | **Average recovery time without notification** | Interruption recovery time without pre-notification / total interruption time |

Source: Development of Techniques for Reconstructing and Operating Water Belt 2016

## Chapter 3: Analysis and Findings

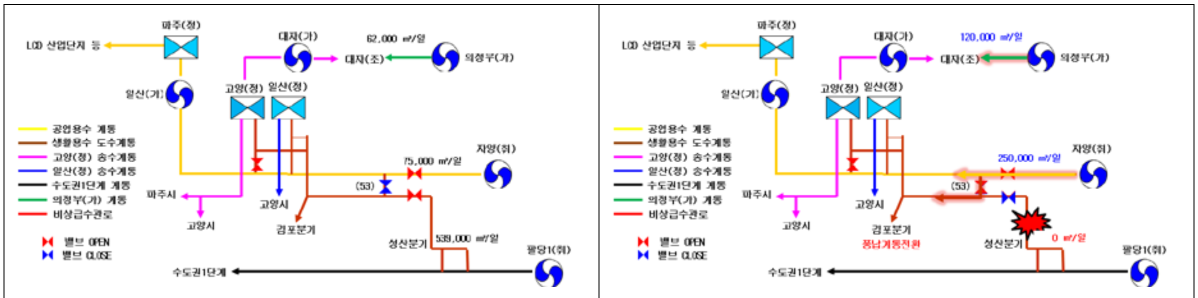
In this chapter, PIs are constructed by using the early gathered data. Next, to verify their appropriateness, this study will analyze PIs by applying on actual managing case of a management office in K-water.

### 3.1 Basic data for analysis

Before constructing PIs, explanation of basic data for analysis is needed. The case is one example related to EWSP and management office in northwestern-province, Go-yang and Paju City. The reason for selection is as follows. First, it is relatively clear to divide the water supply systems in contrast to other departments, because it was established in 1990 with the Il-san Water Supply Project and the primary and secondary Han River Water Supply System Adjustment Project. Second, 12 cases are classified according to representative scenarios such as the accidents on pipeline, power outages and fires. In each case, available supply time was calculated by using the wide-area grid connection and storage capacity, the reservoir of purified water and distributions. As a result, except for scenarios 6, 7, 8 and 9 related to industrial water supply related, most of cases are simulated to be able to supply water more than 20 hours in crisis.

Although, when occur emergency situation, it might be possible to assess stable WSS by only considering the available supply time, this chapter will conduct comprehensive assessment for analyzing of the difficulty of system operation and the scale of damage by using proposed PIs.

***Figure 2:*** A schematic of Emergency Supply Plans in Go-yang city



| Daily | Emergency |
|---|---|

Source: K-water

***Table 4:*** Performance Indicators related to Crisis in IWA

| Scenarios | | Main Methods | Daily | Emergency | Available Time(hr) | Ratio of supply |
|---|---|---|---|---|---|---|
| | | | (1,000m3/d) | | | |
| **CASE 1** | Ja-Yang I | Switch operation<br>(Metro 1st, H. R Tunnel) | 614 | 614 | - | 100 |
| **CASE 2** | Han River Tunnel | Increasing Ja-Yang I<br>Switch operation<br>(K.P, U.J.B B)<br>Use Storage capacity | 676 | 676 | 24 | 100 |
| **CASE 3** | Go-yang P | Connecting IL-San P<br>Use Storage capacity | 382 | 382 | 24 | 100 |
| **CASE 4** | Paju Lines | Use Storage capacity | 177 | 157.5 | 21.4 | 89.0 |
| **CASE 5** | Il-San P | Connecting Go-Yang P and etc. | 382 | 382 | 24 | 100 |
| **CASE 6** | Il-San B | Use #59 Tie and Storage capacity | 330 | 275 | 15.5(13.4) | 83,3 |
| **CASE 7** | After #59 Tie | Use Storage capacity<br>with Customer tank | 153 | 68 | 10.4(13.4) | 44.4 |
| **CASE 8** | Paju P | Use #59 Tie and Customer tank | 153 | 275 | 15.5(13.4) | 83.3 |
| **CASE 9** | Paju P Lines | Use only Customer tank | 153 | 90.5 | 9.1(13.4) | 59.2 |
| **CASE 10** | DaeJa Lines | Switch operation (Metro $5,6^{st}$) | 251 | 251 | - | 100 |
| **CASE 11** | KimPo Lines | Switch operation (Pung-Nap I) | 120 | 120 | - | 100 |
| **CASE 12** | Paju Quality | Settle-Water I<br>Increasing Go-Yang P | 145 | 145 | - | 100 |

Source: K-water

### 3.2 Composition of Performance Indicators on Crisis situation.

Chapter 2 is summarized as follows. First, the publication "Performance Indicators for water supply services" from IWA is one of the most broadly accepted international references in terms of measurement of WSS. IWA published 138 indicators in 2000 at the beginning, and then added 32 additional indicators, making up a total of 170 indicators in 2006. Among them, some indicators, such as pressure and continuity related to crisis are considered for this study. Next, in JWWA Q100, 17 indicators are identified for evaluating "Stable: secure living water stably anytime and anywhere." The main features are that they have several indicators related to earthquake and the ability of crisis response. Lastly, from the previous study at K-water, five indicators for supply stability, which evaluate the adequacy and operational efficiency on grid system of wide-area and local WSS, are considered for this study. The result are shown in Table 5 below.

PI is organized to evaluate the facility conditions and operational efficiency for stable supply on crisis situation. PI 1 evaluates the overall status of system. It is possible to identify the vulnerability on system. However, it may be effective to sum up the cumulative number within a certain period of time. The improved indicators discussed in Chapter 2.3 is reflected as PI 2 to 5. However, by considering the fact that domestic and the industrial water are mixed, this analysis used quantity instead of population, and also, because these PIs evaluates the ability of crisis response, it used 24 hours a day instead of an annually accumulated number. In terms of the public's expectations directly related to customer complaints and quality of service, PI 6 and 7 are able to check the system. Indicators 8 and 9 distinguish the concepts of between interruption and restriction, so that to figure out direct and indirect effects when crisis situation occur. Finally, indicator 10 was selected to easily check the ability of crisis response in each system. The results are shown in Table 6.

***Table 5:*** Composition of Performance Indicators on WSSs in Crisis situation

| Index | Indicators | Main factor | Reference |
|---|---|---|---|
| **PI #1** | Mains failures | Cumulative number of accidents | IWA, JWWA |
| **PI #2** | Available supply amount | Directly limited amount of the accident | K-water |
| **PI #3** | Time with restriction to supply | Calculated on 24-hour of A day basis | K-water |
| **PI #4** | Interruption population | Replaced by amount, if population can't | K-water |
| **PI #5** | Budget for Crisis Management | - | K-water |
| **PI #6** | Pressure of supply adequacy | Number of lower than standard pressure | IWA |
| **PI #7** | Continuity of supply | - | IWA |
| **PI #8** | Population experiencing interruption to water service | Damages of the whole system when 24 hours is not available | IWA |
| **PI #9** | Population experiencing restrictions to water service | Damages of the whole system when 24 hours is not available | IWA |
| **PI #10** | Accident water distribution rate | - | JWWA |

### 3.3 Evaluation of 12 Cases by Using PIs

<table>
<tr><th>구 분</th><th>Current</th><th>PI 1</th><th>PI 2</th><th>PI 3</th><th>PI 4</th><th>PI 5</th><th>PI 6</th><th>PI 7</th><th>PI 8</th><th>PI 9</th><th>PI 10</th><th>Type</th></tr>
<tr><td>CASE 1</td><td>100</td><td>2</td><td>100</td><td>0hr</td><td>-</td><td rowspan="12">-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>91</td><td>Indus</td></tr>
<tr><td>CASE 2</td><td>100</td><td>3</td><td>100</td><td>0hr</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>57</td><td>Dome<br>Indus</td></tr>
<tr><td>CASE 3</td><td>100</td><td>0</td><td>100</td><td>0hr</td><td>-</td><td>-</td><td>-</td><td>61</td><td>0</td><td>73</td><td>Dome</td></tr>
<tr><td>CASE 4</td><td>89</td><td>0</td><td>76</td><td>6hr</td><td>24</td><td>-</td><td>-</td><td>100</td><td>100</td><td>76</td><td>Dome</td></tr>
<tr><td>CASE 5</td><td>100</td><td>2</td><td>100</td><td>0hr</td><td>-</td><td colspan="2">Simulation</td><td>100</td><td>0</td><td>48</td><td>Dome</td></tr>
<tr><td>CASE 6</td><td>83</td><td>1</td><td>64</td><td>9hr</td><td>36</td><td>-</td><td>-</td><td>-</td><td>-</td><td>44</td><td>Indus</td></tr>
<tr><td>CASE 7</td><td>44</td><td>0</td><td>44</td><td>13hr</td><td>56</td><td>-</td><td>-</td><td>-</td><td>-</td><td>44</td><td>Indus</td></tr>
<tr><td>CASE 8</td><td>83</td><td>0</td><td>64</td><td>9hr</td><td>36</td><td>-</td><td>-</td><td>-</td><td>-</td><td>44</td><td>Indus</td></tr>
<tr><td>CASE 9</td><td>59</td><td>1</td><td>59</td><td>10hr</td><td>41</td><td>-</td><td>-</td><td>-</td><td>-</td><td>44</td><td>Indus</td></tr>
<tr><td>CASE 10</td><td>100</td><td>3</td><td>100</td><td>0hr</td><td>-</td><td>-</td><td>-</td><td>0</td><td>0</td><td>130</td><td>Dome</td></tr>
<tr><td>CASE 11</td><td>100</td><td>0</td><td>100</td><td>0hr</td><td>-</td><td>-</td><td>-</td><td>0</td><td>0</td><td>36</td><td>Dome</td></tr>
<tr><td>CASE 11</td><td>100</td><td>0</td><td>100</td><td>0hr</td><td>-</td><td></td><td></td><td></td><td></td><td></td><td>Resour</td></tr>
</table>

***Table 6:*** The result of Evaluation on 12 cases by PIs

### 3.4 Analysis from the Result

#### 3.4.1 Basic Analysis

This part uses the result by PI 1 to 5 and 10. Analysis of accidents from 2013 to 17 by PI 1 shows that accidents occur most frequently in CASE 2 and 10, and through PI 2 to 4, CASE 4 and 6 to 9 of supplying industrial water are vulnerable in crisis situations. However, this analysis only uses the limited total quantity on system at the time on accident instead of the total demand which is used at existing cases. As the result of PI 2 to 4, most figure on cases are similar to the current applying the previous method, but overall the scale of damage is increased.

PI 5 is better to apply to other water service providers such a local government provider. The Ministry of Public Administration and Security is establishing and managing 'Disaster Safety Management Joint Application System' in accordance with Joint Usage Standards for Disaster Managers (2016). In addition, K-water is organizing a crisis-response budget at its head office. The management department uses the budget to deal with crises when occur crisis.

Finally, PI #10 indicates the amount of available distribution compared to the total limited amount by crisis. It is possible to confirm the stability of system on risk. The higher the value, the more stable supply during recovery time, and also it may be more than 100% depending on condition of system. CASE 1 and 10 can be interpreted as having the good ability of response on crisis, because these possess spare amount for suppling relative to the scale of accident.

### 3.4.2 Pressure and Continuity

If 24 hours supply is inadequate, the impact of the accident is so great that it should be managed like disaster. In this case, the analysis of the Pressure and Continuity indicators are likely to be meaningless, because they are rarely the benefits in skilled operations. Therefore, for these PIs, CASE 3 which is available to supply for 24 hours is used by EPANET.

To simplify analysis, the simulation was performed under following conditions. The results are shown in Figure 2.

(1) Apply the condition of booster facilities in the Il-san purification plant at 2015

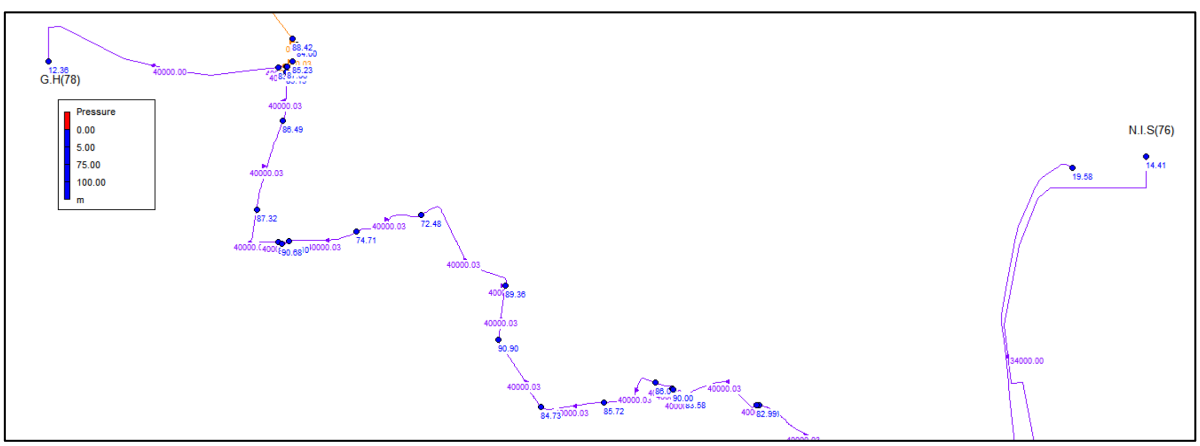
(2) Meet the daily demand at New Il-San reservoir (N.I.S)

(3) Include the supply amount of Paju cogeneration plant (P.C.P) to Gyo-Ha (K.H) reservoir

(4) Use single-time simulation of 2015 daily average demand in 2015

(5) Base appropriate pressure on point of water supplying, but used inflow of the reservoir.

***Figure 2:*** Simulated Result on CASE 3 by using EPANET



A although the minimum pressure is specified at 1.5kgf/cm2 in the waterworks facilities standard, when simulation is performed by applying normal condition, it is supplied at lower pressure of 0.47kgf/cm2 and 0.89kgf/cm2 than the standard in Table 7. In addition, if supplier try to meet the pressure criteria at two major points, the capacity of supply falls from 85,000m3/d to 70,000 m3/d.

***Table 7:*** Demand change according to water pressure

| **Setting Pressure,** kgf/cm2 | **G. H** | | **N. I. S** | | **TOTAL** | **NOTE** |
|---|---|---|---|---|---|---|
| | **Pressure** | **Supply, m3/d** | **Pressure** | **Supply, m3/d** | | |
| **Normal condition** | 4.70 | 51,000 | 8.85 | 34,000 | **85,000** | - |
| **P: 0.5** | **0.03** | **57,000** | 5.51 | 34,000 | **91,000** | - |
| **P: 1.5 for N. I. S** | 13.00 | 39,000 | 14.88 | 34,000 | 73,000 | - |
| **P: 1.5 for N. I. S and G. H** | **14.86** | **36,000** | **16.25** | **34,000** | **70,000** | - |

Reservoirs, in view of supplier, function as temporary storage for the stability of supply system and also a buffer to irregular patterns of receiving. According to simulated result in Table 7, if the supply water pressure is set to 5kgf/cm2, it can supply up to 91,000m3/day. In terms of response on such as crisis situation, it might be necessary to try to agree on the minimum water pressure between the supplier and customer. Nevertheless, in the perspective of customers like local governments, it is essential to actively cope with the patterns of citizens' receiving. Especially in the case of direct water supply areas, it is possible to raise inconveniences by not meeting water pressure.

In order to accurately calculate the continuity, the time pattern must be applied to simulation. This study examined only the necessity of PI 9 by using maximum supply amount per time. Generally, to calculate maximum supply amount per time, we should multiply the maximum demand per day by 1.3 of index on metropolitan and industrial cities.

***Table 7:*** Demand change according to Maximum supply amount per hour

| | **Daily** | **Maximum per day** | **Maximum per hour** | **Increase rate** |
|---|---|---|---|---|
| **N. I. S** | 34,000 m3/d | 41,000 m3/d | 53,300 (39,000 of G.H) | 56% |
| **G. H** | 51,000 m3/d | 60,000 m3/d | 78,000 (2,000 of N.I.S) | 53% |

Table 8 shows that if each receiving point such a reservoir receives maximum amount per time, others are impossible to get the demand amount per day. When N.I.S receive of 53,000 m3/d, G.H falls down 51,000 m3/d to 39,000 m3/d. This result was able to analyze to supply minimum amount due to reflecting the characteristics of reservoir that can receive until the residual water pressure reaches zero. However, in systems on direct supply area, interruption might happen at some high elevations. As a result, complaints such as civil claims and negative press reports can become prevalent, indicating that even if 24-hour supply is possible, it needs to be set as the continuous management section.

### 3.4.3 Interruption and Restriction

This analysis applied only CASE 3,4 and 5, which supplies domestic water, to confirm the impact for population. As mentioned above, the indicators presented by the IWA distinguish between interruptions and restrictions.

In the case of interruption, the standard at EWSP only estimates the size of the affected population by remaining amount. However, this methodology is difficult to apply in actual situations, because it is only possible when the interruption zone is minimized to a systematic transition of system. That means, if the supply eventually stops, all of the supply areas should be assume such a suffering from interruption damages. On the other hand, as in PI 6 and 7, even if customers normally receive water in crisis, total reservoirs might be controlled by supplier who is taking charge of emergency responses. For example, if the amount of receiving at G.H increases too sharply in CASE 5, supplier needs to control G.H for normal suppling to N.I.S. Although they already have a coordinative system, it means that the service of restricted supply is provided to customers.

Considering the above premise, the results from PI #8 and 9 are as follows. According to PI #8, CASE 4 shows that all of existing supply areas associated with an accident can cause stop. In addition, during recovery period of accident, it is also possible to recognize restriction of water supply. CASE 3 and 5 show that all existing supply areas are subject to restricted supply, even though the emergency supply rate from PI #2 is 100%. It means that decision makers or planners need to be aware of this result and monitor that value in order to manage potential risk factors such as complaints and negative press reports.

## Chapter 4: Conclusion and Policy Recommendations

This study examined performance evaluation methods of the stability of WSS which can supply stable water in a crisis situation. In order to composite indicators, we reviewed several previous studies, such as related institution and international publications, IWA, and JWWA, and then, were able to review these indicators related to water supply on crisis situation.

As a result, 10 indicators were selected, including continuity, pressure, the concept of difference between restriction and interruption, and so on. Furthermore, by applying these directly to the management office in the northwestern part of Gyeonggi province, this study was able to diagnose the crisis response and verify the effectiveness of PIs.

Most indicators are considered to be used to confirm stability and responsiveness in crisis. Although the analysis figure of PI # 2~4 is lower compared to existing indicators, it has overlapping concepts and needs to be selectively applied.

PI #6 to 9 are meaningful indicators to objectively estimate the scale of damage and to present the need for management of potential risk factors when operating EWSP. Although there were not enough examples to apply for analysis, if we consider both functions of pressure and demand, and the maximum amount of change by time, this case study can confirm that there are several constraints in operation. Especially, PI 8 and 9 in Case 3,4 and 5 show that even if the actual supply interruption did not happen, all customers can get restricted, and moreover, are easily exposed to stop-supply if the rate of supply is 80%. In the case the direct water supply zone that is mixed with local waterworks, it will be possible to make a detailed diagnosis using these indicators.

One of the limitations is that, if total supply is mixed with industrial water, it is necessary to make numerical adjustment to compare the financial damage of the house population and the industrial complex on the same line. Although there were not enough examples to apply for analysis, Other thing is that, it is necessary to test more various cases to exactly utilize some indicators. That tests should use receiving patterns at each main point and especially, include some way of supplying water to customer, such as directly or not.

Policy Recommendations through this study are as follows. First, in addition to physical connectivity and supply capacity in EWSP, it will be necessary to expand the evaluation methods to identify crisis factors affecting the normal operation. These include customer service and complaints, as well as negative press reports. As the result of case study, although it is possible to supply water within the recovery period of, especially 24 hours, vulnerability exists in overall operation process. These vulnerabilities, such as direct supply interruptions can degrade the external image of suppliers and can lead to changes in the company's management evaluation numbers based on customer assessments

Second, it is necessary to examine the method of minimizing the interruption zone as shown in the concepts of PI #8 and 9. Although there may be a controversy over priorities, it is effective for managers to intensively manage and operate follow-up measures such as 2nd and 3rd. If the supply is insufficient for six hours, it will be possible to design some ways of control on water supply area and to evaluate it with PI #8.

Finally, the collaboration system with customers considering WSS operation in risk situation can also have a great impact on enhancing crisis response, so further research that can be reflected in the evaluation indicator group is also required. This comes from the fact that, as mentioned above, not only the adjustment of supply interruption area but also the restriction of water and the maintenance of appropriate pressure should be accompanied by a high degree of cooperation and understanding from customers.

## References


Sun Young Park., Mun Hyun Ryu., Seung Hoon Yoo., 2015. Economic Benefits of Double-lined Water Supply System in Gumi, *Jaejeongjeongchaegnonjib*, 17- 4, pp.21-42

Husnain, H., Sadiq, R., & Tesfamariam, S. 2013. Performance indicators for small- and medium-sized water supply systems: a review. *Environmental Reviews*, 22(1), 1-40. NRC Publishing, Canada.

Alegre, H., Hirner, W., Baptista, J.M., and Parena, R. 2000. Performance indicators for water supply services, Manual of Best Practice Series, IWA Publishing, London.

Helena Alegre, Jaime M. Baptista, Enrique Cabrera Jr et al., 2006. Performance Indicators for Water Supply Services, IWA Publishing, London.

K-water. 2016. Development of Techniques for Reconstructing and Operating Water Belt.

JWWA Japan. 2005. Guidelines for the management and assessment of a drinking water supply service (JWWA Q100)

Berg, C., and Danilenko, A. 2011. The IBNET water supply and sanitation performance Blue Book, The International Benchmarking Network for Water and Sanitation Utilities Data book, Water and Sanitation Program, The World Bank, Washington D.C., p. 58849.

Ministry of Land. 2015. 2025 sudojeongbi gibongyehoeg(gwang-yeogsangsudo mich gong-eob-yongsudo) byeongyeong bogoseo [2025 the change report of master plan for development of water supply on multi-regional and industrial water].

Choi, Taeyong. 2007. Evaluation of the effectiveness of performance indicators for waterworks and development of the application system. University of Seoul.

K-water. 2015. gwang-yeog mich gong-eob-yongsudo anjeonghwasa-eob ‘15nyeon Annual Report mich ‘16nyeon chujingyehoeg [Multi-regional and Industrial Water Supply Stabilization Project 2015 Annual Report and 2016 Implementation Plan]

K-water. 2016. gwang-yeog mich gong-eob-yongsudo anjeonghwasa-eob ‘16nyeon Annual Report mich ‘17nyeon chujingyehoeg [Multi-regional and Industrial Water Supply Stabilization Project 2016 Annual Report and 2017 Implementation Plan]

K-water. 2016. Development of Techniques for Reconstructing and Operating Water Belt.

Ministry of Public Administration and Security. 2016. jaenangwanlijawon-ui gongdonghwal-yong gijun [Joint use standard of disaster manager]. http://www.law.go.kr/admRulInfoP.do?admRulSeq=2100000092965

K-water. 2018.「sig・yongsubun-ya」 wigigwanli pyojunmaenyueol ["Drinking and Using water Sector" Crisis Management Standard Manual].